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RECENT GEOLOGY OF SPITZBERGEN

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The Spitzbergen archipelago consists of many islands upon a submerged plateau. The largest, known as West Spitzbergen, is not far from 300 miles long from north to south, and its southern point, South Cape, is in N. L. $76^{\circ} 20'$, about 150 miles north from the outlying Bear or Cherry Island. The western coast is indented by bays extending inland 20-80 miles. The surface, as seen from the western side, is a succession of plateaux, 300-900 feet near the coast, and rising to 1,600 feet farther inland, with irregular peaks, 2,000-4,000 feet high, scattered over it.

The climate of the region in middle Tertiary times was not more severe than that of our latitude, and familiar types of tertiary deciduous trees, described by Heer and later by Nathorst, occur abundantly at a locality about 8 or 10 miles south from Icefjord. The rainfall up to a comparatively recent period must have been abundant to bring about the baseleveling of the area and afterward to cut the deep valleys, filled in later times by the glaciers. The rainfall now must be insignificant, as during the very brief summer the temperature seldom rises above 4° C.

In West Spitzbergen, glaciers begin at a few miles north from South Cape and, at Horn Bay, several come down to the water, some of which seem to reach back to the inland ice north from that bay. On Recherche Bay, a branch of Bell Sound, and about 90 miles from South Cape, two fine glaciers remain: one on the west side coming down from Bell Mountain, 4 or 5 miles away, and another on the southeast, which extends southward to the high inland ice. Between these is a deep valley, in whose lower portion no ice remains. Northward to Icefjord, 20 or 25 miles, ice is present in notable quantity on the upland, but reaches into few of the valleys, many of which are open from the sea almost to the plateau. On the northwesterly side of Icefjord, a vast glacier, beginning at 6 or 7 miles from the sea, extends almost unbroken along the coast from Safe Harbor to Cape

Bohemian, about 25 miles, and stretches back, 12 to 20 miles, to a high ridge, where it may be continuous with the névé basin beyond. This glacier appears to be without a name; it should be dedicated to Nathorst.

The climatic conditions of Spitzbergen have undergone such change since the glacial period that for a long time the waste has exceeded the snowfall; evidence of loss is distinct everywhere. Bear Island, 150 miles south from South Cape, while in some respects harsher in climate than is West Spitzbergen, now shows no trace of glacial ice, though a fine trough coming down to sea-level at the north-west corner proves its former existence. Both glaciers in Recherche Bay project into the water with an abrupt face, estimated to be about 150 feet high, and fully one mile long in one, two miles in the other; but each of them is retreating on one side, where the boundary curves back on the shore and the surface is gently rounded. This retreat is especially marked in the western glacier, whose lateral moraine on the northerly side extends far out into the bay, while the moraine on the southerly side, medial between it and the greatly diminished middle glacier, is the hook behind which whalers have their anchorage. Even in the ice-wall the loss is notable; for on the face of the western glacier a great recess appears. A similar story is told by the vast Nathorst Glacier on Icefiord, whose retreat is especially marked on the westerly side near Safe Harbor; while between Bell Sound and Icefiord one sees along the coast the long trough-like valleys, almost wholly devoid of ice, but owing their form to the passage of glaciers. The presence of such fiord valley on the sides of Icefiord, as well as dying glaciers at the heads of that bay's branches, indicate that, at one time, confluent glaciers filled Icefiord and extended seaward. It is equally clear that the same condition existed on Bell Sound. So that the extensive glaciers of West Spitzbergen, like the small glaciers of Norway, must be regarded merely as remnants of a great sheet covering the whole land and extending, finger-like, through gorges into the sea.

The valleys are not broad, with gently rounded outline, like very many of those along Storfiord north from Marok, but they have abrupt walls, resembling those of the deeper interior fiords along the Norway coast. In some of the Norwegian valleys, especially along Storfiord, the glaciers have changed the form of the valleys far beyond

the usual trough, but such evidence of extended erosion is not distinct in those Spitzbergen valleys seen by the writer. Possibly the evidence is more satisfactory farther up those valleys where the floor becomes somewhat abrupt. On Advent Bay, just above a fragment of the terminal moraine forming the "hook" which protects the anchorage, there is a low wall of soft Jurassic rock rising sharply to about 20 feet above the water, and from its edge the floor reaches back to the bluff. This wall is somewhat higher than the marshy floor of Advent Dale, 3 miles away at the head of the bay. It seems strange that the ice did not remove this soft material. It is true that the movement could not have been rapid, as the slope of the floor is very gentle, and the place is less than a mile from the mouth of the bay where this glacier joined the main stream; but, unless the ice were heavily laden with débris, there should have been motion enough to cut away this petty obstruction.

There has been little erosion by water since the ice retreated, and the waste has been due to changes of temperature, which are superficial. The entry of the Spitzbergen Coal Company, about 200 feet long at the time of the writer's visit, was still in frozen coal. Summer heat thaws the ground to only a few inches, yet suffices to encourage growth of humble flowering plants, and an accumulation of peat, which makes tramping a matter of difficulty.

In the later Tertiary the surface of Spitzbergen must have been much nearer sea-level than now, to admit of the baseleveling which bears no relation to the position of the tilted, faulted, and contorted rocks, and which removed so much of the earlier Tertiary deposits. Comparatively rapid elevation must have succeeded, during which the deep valleys were digged out to be filled in later times by glaciers. Soundings reported on the English Admiralty Chart indicate that at one time the surface stood much higher than now. Possibly the later depression may be related in some way to the disappearance of the ice.

Northeast Land, a glaciated area of perhaps 20,000 square miles, forms with some outlying small islands the northern portion of the archipelago, and is separated at the southwest from West Spitzbergen by Hinlopen Strait. Westward from Northeast Land and its islands, the depth increases very slowly, the soundings showing 8-20 fathoms at 10-20 miles from the land; but the course of the valley of Hinlopen

Strait seems to be well marked, the depth increasing to 72, 90, and 200 fathoms, with 755 at 30 miles farther. As far as to the 200-fathom point high land is alongside, the depth being only 8-40 fathoms, while farther out toward the deepest sounding along the line of the strait the soundings eastward from that channel indicate a submerged dissected plateau.

Going westward 60 miles, one finds north from West Spitzbergen another area of soundings showing similar conditions. Wilde Bay extends southward from the north coast for 90 miles; forty miles up its depth is 30 fathoms; at 10 miles from the sea it is 90; but a submerged moraine reduces the depth at the mouth to 55-72 fathoms. Liefde Bay is just west, with, as its western boundary, a broad low area, about 100 square miles, apparently moraine stuff. At its mouth, where it adjoins Wilde, the depth is 93 fathoms. The course of the united bays can be followed northwestwardly until its depth becomes 150 fathoms, and at 15 miles farther 505. This is inclosed on the west by elevated land, covered by 42-70 fathoms and cut by valleys, some of which are tributary to the Wilde-Liefde, while others are tributary to a shallower valley at the west, which is but 360 fathoms deep at 10 miles west from the 505-fathom cast, and only 390 at 30 miles farther, or 120 miles northwest from Liefde Bay. Still farther west is a deeper valley with a depth of 235 at 27 miles, 300 at 40, and 730 at 115 miles from the northwest corner of the island.

Going southward along the west coast, one finds the long island known as Prince Charles Foreland, separated from West Spitzbergen by the narrow Foreland Sound, shallow and 8-10 miles wide. The depth of the sound at its mouth is 27 fathoms, but its course is clear, for the depth becomes 120 fathoms at 15 miles north. Westward from this the soundings are too few to be of much value, but the greatest depth at 75 miles from the coast is only 200 fathoms, though farther south the 300-fathom line is at 45 miles and the 500-fathom line at 51 miles from the coast. The abruptness of the change from 200 to 300 and then to 500 fathoms suggests that this line of soundings falls off into a valley.

Icefiord is much deeper than any of the bays at the north; it is 120 fathoms at 8 miles up, and 215 at its mouth, while at 60 miles west-southwest the soundings show 600 fathoms, though at a few miles north the depth is but 93-110 fathoms. At a few miles south,

due west from Bell Sound, the depth increases very gradually for 40 miles to 100 fathoms, but the course of the Bell Sound channel is in southwest direction, 839 fathoms being reached in 70 miles, and only 15 miles west from a line of soundings showing 90-130; a sounding of 160 fathoms between this line and the shore suggests the existence of a tributary valley there. West from South Cape the depth becomes 118 at 45, 523 at 55, and 743 fathoms at 65 miles.

Farther south the 700-fathom limit is between 60 and 70 miles west from a line joining South Cape and Bear Island; eastward from this line the depth decreases within 10-15 miles to about 200 fathoms, which is the depth on a broad strip of 10-15 miles; thence eastwardly for nearly 200 miles the depth, except along well-defined lines, varies between 20 and 50 fathoms. In 225 miles northeast from Bear Island the depth exceeds 35 fathoms only three times; while between this broad strip and the larger islands at the northwest one can trace deep channel-ways marking the westward drainage. An elevation of 250 feet would unite all the great islands to each other and to Bear Island, now 150 miles from South Cape, the nearest point.

The long channel-ways at the north traceable between walls until they reach a depth of 390 in one case, 505 in another, that of Icefjord traceable to 600 fathoms, with only 100 fathoms at 15 miles away on each side, as well as the relation of the 700-fathom line to the direction of the coast, seem to leave little room for doubt that at one time the coast line lay not far from that marked by the depth of 700 fathoms. The details of soundings do not permit anything further at present. Icefjord, now only 8 miles wide at the mouth, was a broad valley beyond the present coast line, 20 miles wide at 70 miles away, with its bounding walls rising 2,000-3,000 feet above its floor; the valley of Hinlopen Strait as well as that of Wilde-Liefde Bays must have extended in like manner to more than 100 miles beyond the present coast line; and the Spitzbergen plateau was a triangular area extending from beyond N. L. 82° southward to an unknown distance beyond Bear Island, not less than 700 miles from north to south; the width in N. L. 81° much exceeded that of the area given on the Admiralty Chart, which is about 400 miles wide. The writer had no access, during the preparation of this note, to the results obtained by the several recent expeditions to Franz Josef Land; but Nansen's description of the fiord features of the inlets

there, as well as the similarity in geological character between West Spitzbergen and a portion of Franz Josef Land, recognized by Nathorst, suggests that that area, now not more than 120 miles east from Northeast Land and extending northward to about 84° , may have been continuous with the Spitzbergen area, and may have reached as land far toward the North Pole.

Submerged moraines in many of the bays mark halts in recession of the ice. Where the branches of Red Bay on the north shore come together the depth decreases from 50 fathoms above to 6 and 7, with a narrow strip of 33 fathoms on one side; the depth increases to 78 farther down, but at the mouth of the bay is a bar with 8-23 fathoms. Near the head of Foul Bay the sounding is 61 fathoms, but at the mouth there is shallow water; Magdalena shows 50 fathoms near the head, but lower down it is blocked by shoals with about 30 fathoms on each side. Sassen Bay, the east branch of Icefiord, is 100 fathoms deep at 10 miles above its mouth, but is barred by a moraine with 49-63 fathoms. No such barring appears in Icefiord, which deepens steadily to 215 fathoms at its mouth; but the barring is distinct in Recherche Bay. Similar conditions exist at many other localities, and explain the absence of icebergs off the plateau. But in any case, the ice is not thick enough to give off imposing blocks, there being in all probability not more than 500 feet at any place where the wall comes down to the water.

That the great subsidence was succeeded by elevation—which may be going on—is proved by terraces in the moraine stuff on Icefiord and Recherche Bay, as well as at other localities along the coast. No opportunity was found for measuring these, but they are as characteristic as are those at Naes, Odda, and Marok as well as elsewhere in Norway. Sandy beaches were seen south from Icefiord.

The effect of wave-action is well shown on Bear Island, which has suffered severely on the east and west coasts. At one time a glacier had its origin on the southeasterly side and flowed to the northwest corner. The waves have cut away the névé area, and the trough is open at the east; as the coast on the westerly side is diagonal to the course of the trough, the bold rocky bluff at the southern point falls off northwardly until at the northwest corner the whole wall has been removed and the valley bottom is now the shore line.